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THE BOTANICAL REVIEW

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THE TUNG-OIL INDUSTRY

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The tung tree (*Aleurites fordi* Hemsl.) was introduced in 1905 into the United States from China by the Office of Foreign Plant Introduction of the United States Department of Agriculture. The China wood-oil or tung-oil tree is one of the most interesting of many thousands of plants introduced from foreign countries by the Department. The name "tung-oil" has come to be the one generally used in the United States. The oil expressed from the seed is one of the best drying oils known, and its numerous uses are discussed in this paper.

DESCRIPTION OF THE TUNG TREE AND RELATED SPECIES

The tung-oil tree belongs to the Spurge family, Euphorbiaceae, of which there are about 4,000 species divided among some 220 genera. In this family are such familiar plants as *Phyllanthus, Croton, Acalypha,* castor bean (*Palma Christa*), *Euphorbia, Jatropha* and *Poinsettia.* The tung-oil tree belongs to the genus *Aleurites.*

There are five species in the genus *Aleurites.* These rank in hardiness with respect to cold in the following order, according to observations in Florida: *fordi, montana, moluccana, cordata* and *trisperma.* Apparently, *cordata* and *trisperma* can be grown only in the warmest parts of Florida, while *moluccana* has been observed growing in slightly colder areas of the State. *A. montana* does not stand as much cold as *fordi,* although there are three trees on the Florida Experiment Station grounds at Gainesville, two of which were planted in 1924; they suffer more damage during low temperatures, however, than *fordi* nearby. After *montana* attains five or six years' growth it seems to withstand more cold than during the first three or four years after the trees have been transplanted or as seedlings in the nursery for the first year or so.

There is a small planting of *trisperma* on the Forida Agricultural Experiment Station grounds of the Sub-Tropical Experiment Station at Homestead, and these seem to be growing fairly well. They are too young at this time, however, for any predictions to be made as to their commercial possibilities in future years.

Aleurites fordi Hemsl. (tung-oil tree) is the principal source of tung oil in commerce and is the one extensively grown in the United States. It is a native of central and western China, and there the oil is known as wood oil, and the tree as tung-shu.

The tung tree is deciduous and grows to an average size of 25 to 40 feet. The leaves are more or less heart-shaped, though often with three more or less distinct lobes, and are rather large and dark green in color. Leaves of both shapes are found upon the same tree with the lobed leaves often occurring predominantly on young trees. The leaves shed during autumn and the tree remains dormant throughout the winter months if cool or cold temperatures prevail.

The tree is monoecious, the flowers massed in great profusion on the terminals of twigs. Both pistillate and staminate flowers are produced in the same cluster. There is a great preponderance of staminate flowers in approximately a 60 to 1 ratio to pistillate flowers. The individual blossom is white and tinged or striped with pink in the throat, except on an occasional tree which has white flowers. The whole mass of flowers is borne in a large loose cyme with a pistillate flower as the central or apical flower of the cyme, all lateral blossoms being staminate, except in the cluster type in which one to several pistillate flowers are in lateral positions in the same flower cluster. The staminate flowers usually carry five petals, while the pistillate frequently has six or more.

The flowers usually appear just ahead of the leaves. The time of their forcing is governed largely by temperature during winter months. Consequently, at Gainesville, Florida, the first blossoms appear on various dates from the middle of February to April 10, depending on the season. A cold period in November or December, followed by four or five weeks of warm weather, frequently forces the buds into growth earlier than when continued cool or cold temperatures are experienced. Under such conditions of bud growth, freezing temperatures cause severe damage to both fruit and vegetative buds, which seriously curtail production. Such was the case in 1939 when the trees had begun to force growth early and the buds were killed by a freeze on February 22.

Because of the great preponderance of staminate flowers in close proximity to pistillate flowers in the same flower cluster, adequate pollination is amply provided. Owing to this characteristic there is probably a great amount of self-pollination in open-pollinated flowers. Progeny seedlings of certain trees reproduce the characteristics of such trees in relatively high percentages, which would indicate that there may be a high percentage of close pollination.

Perfect flowers are rare, although instances have been recorded of such occurring. This is not of any special importance, as no pollination troubles have yet been reported.

The fruit is from two to three inches in diameter, olive green in color, turning to a dark or deep brown when fully mature. As with the pistillate flowers, the fruit may be borne singly or in clusters of two or more. This has given rise to a common distinction of types as "single" or "cluster", depending on how the fruit is borne. The fruit is generally more or less round in shape, somewhat like a small apple, although some trees may produce oblong fruit.

The fruit consists of an outer portion or husk, and contains usually from three to seven seeds. When fully mature it falls to the ground, and when it becomes fully dry it is ready for harvest which is accomplished by picking up the fruit and storing it in covered sheds or bins to keep it dry until hauled to the mill.

The growth characteristic of the tung tree presents many perplexing problems in horticultural practices. In general, growth consists of a succession of whorls of branches spaced over a small area of the stem, or they may be fairly well distributed, but, in almost all instances, there is some space between these branched areas. Growth is quite vigorous on suitable soils with adequate nutrition and moisture, a seedling frequently attaining five to seven feet in a single growing season.

Aleurites montana (Lour.) Wils. is known as mu-oil tree, mu-yu shu and abrasin. In America it is referred to generally as *montana*. In some respects it resembles *fordi* but is decidedly more upright in growth, and, judging by the size of the oldest trees in Florida, it apparently attains a greater height with lesser proportionate spread. The leaves are normally 3- to 5-lobed, some cordate, with prominent cupped glands at the base of each sinus and at the apex of the petiole.

The flowers are pure white and the ovary 3- to 5-celled. There

is a rather strong tendency to dioeciousness in *montana* which is quite different from the other species; for example, this characteristic is not pronounced in *fordi.* Trees at Gainesville and other locations in Florida are divided as to type of flowers produced, some being predominantly staminate and others pistillate. The fruit is about one and a half to two inches in diameter, distinctly angled with prominent, irregular veining on the surface; hull very hard; three to five seeds normally, which are brown and smooth.

Although *montana* and *fordi* are said to be found together in some Chinese provinces, *montana* is reported to be the prevailing species in southern China. *Montana* seems to be well adapted to sandy soils, as the trees at Gainesville and other locations under somewhat similar conditions of soil have made very satisfactory growth. It is considerably less resistant to cold than is *fordi.*

The fruit of *montana* yields an oil which chemists find to be chemically the same as that expressed from *fordi.* It is reported that *montana* oil makes up a portion of the tung oil shipments from China.

Aleurites moluccana (Willd.) (*A. triloba* Forst.) is commonly known as lumbang, kukui, candlenut and varnish tree. This species produces fruit which yields about 18% oil that might be used for some of the same purposes as tung oil, but it is said to be of lower quality. The tree is less hardy with respect to cold than either *fordi* or *montana,* and can be grown only in areas of Florida without severe frosts.

The *moluccana* tree grows with large spreading branches; leaves are large, ovate-acuminate, short-lobed, rusty pubescent below; flowers, many and small, occur in paniculate cymes, four to five inches long; there are 15 to 20 stamens, and a 2- or 3-celled ovary. The fruit is two to three inches in diameter, containing large, rough, walnut-like seeds. *Moluccana* is probably native to the Malay region but is now reported to be widespread in the tropics.

Trees growing in Florida in Dade, Lee, Palm Beach, Brevard and other southern counties have survived over a period of years, while trees at Gainesville have been killed by cold. On Merritt's Island in Brevard County a candlenut tree has shown great vigor in growth, being some 30 feet in height and bearing heavy crops of fruit.

There is very little information at present regarding the com-

mercial possibilities of *A. moluccana* in the United States. It is certain, however, that this species can be grown only in the warmest parts, when viewed from a temperature relationship.

Aleurites cordata R. Br. is native to Japan and is commonly known as the Japan wood-oil tree. The tree grows to a height of 25 to 30 feet. Leaves are broadly ovate, acuminate, 3–5 lobed or toothed. Petals oblong, ¾ inch long, hairy at the base; stamens 8–10; ovary 3–4-celled; fruit warty; seeds about the size and shape of castor beans. Cultivated in Japan south of 40° latitude and in Formosa. The Japan wood-oil obtained from the fruit of this species differs from tung oil in some important properties, according to reports of chemists working on oils.

A. cordata has not withstood the winter temperatures prevailing at Gainesville, Florida. However, there are a few small trees in warmer parts of southern Florida. Apparently, this species offers little commercial possibilities in the United States at present. However, future tests may bring out certain facts which may make it possible to grow it in some areas.

Aleurites trisperma Blanco (*A. saponaria* Blanco) is the banu calag or soft lumbang tree of the tropics. It is a native of the Philippines and is the source of an oil which has merits for certain purposes. Leaves more entire than those of *A. moluccana*. Flowers with 7–10 stamens, 3–4-celled ovary. Fruit containing smooth seed. Trees of this species have been planted in a limited way in Dade County, Florida, and they have made moderately thrifty growth. An experimental planting in 1935 at the Sub-Tropical Experiment Station of the Florida Agricultural Experiment Station system at Homestead has made promising growth.

IMPORTANCE AND USES OF TUNG OIL

Tung oil is one of the most important drying oils known and is used in large quantities in a great many industries. It has been in use for many centuries in China and is today extracted in large quantities by the same crude processes that have been in use for hundreds of years. The Chinese use the oil in many ways but most extensively in paints and waterproofing materials, as in other countries. Crude grades of tung oil are used to coat the Chinese boat or junk instead of covering it with paint. The residue after the oil is expressed from the nuts is used to make a caulking material

for boats. This is accomplished by burning the residue to a soot which is then mixed with the oil to form a paste to make the caulking substance. Oil is mixed with lime and bamboo shavings to make another caulking material which the Chinese use.

In China the oil is also used in its natural state as a protective covering for houses, furniture and other woodwork. Many other uses include waterproofing material for masonry, cloth shoes, clothing, baskets, *etc.* The paper of which Chinese umbrellas are made is waterproofed with tung oil, which accounts for the fact that it sheds water. The oil is also used in the manufacture of India ink. The Chinese take the residue after the oil has been expressed and apply it as a fertilizer for many of their crops.

In America, tung oil is used in the manufacture of varnishes, enamel paint, floor paint, flat wall paint, paint driers, and with resin to make waterproof or spar varnishes. It is also used in the manufacture of oil cloth and linoleum and for waterproofing cloth and many other articles. It is used with aluminum oxide to make aluminum tungate, a fireproofing and waterproofing material. The electrical industry utilizes large quanutities in making insulating compounds for cables, dynamos, motors, *etc.* Lacquer or substitutes for shellac are made by utilizing the fatty acids. Copal gums, no longer available in sufficient quantities to meet the needs of paint and varnish manufacturers, have largely been replaced with tung oil.

There has been an increasing demand for tung oil in industry in America and other countries. However, American industries of various kinds use more tung oil than those of any other one country. Extensive research has been carried out to develop methods whereby it can be utilized as a substitute for linseed oil in ordinary paints. This has resulted in increased use of tung oil.

Tung oil is important in connection with many phases of the defense program in the United States and her Allies. Consequently, since the United States has become involved in war it is understood that steps have been taken to conserve the supply of tung oil for defense purposes. To this end the Government has the full, wholehearted cooperation of American growers and American industry.

Tung oil paints give a glossier finish than linseed oil paints, being much more like enamel in this respect. Therefore, they provide a smooth surface which can be easily cleaned. It is said that they are somewhat more resistant to fungus attacks than ordinary paints.

SOURCES OF TUNG OIL

The principal source of tung oil has been China. Total annual imports into the United States, according to the Bureau of Foreign and Domestic Commerce, United States Department of Commerce, from 1925 to 1940, inclusive, varied from 83,004,000 to 174,885,000 pounds. From January 1 to September 30, 1941, 25,894,000 pounds were imported. There has been a reduction in the quantity imported during the last three years, due to war conditions.

The existing situation regarding the supply of tung oil stocks for American manufacturing concerns has brought about an abnormal condition with reference to price of oil. Consequently, tung oil is now selling at a price much higher than that received before the present emergency. From 1923 to 1929 the price of imported oil averaged about 12 cents per pound; after 1929 the price began to decline until it reached a low of about four cents per pound in 1933 and 1934. After this there was some increase which was only slight until about 1938 when the price was much higher than that received from 1923 to 1929.

American production furnishes only a very small part of the oil required by American manufacturers. However, the supply is gradually increasing and in 1940 Florida plantings produced approximately 10,000,000 pounds of fruit from which was expressed about 1,600,000 pounds of oil. The total for the entire area of the United States in which tung plantings have been made was about 25,000,000 pounds of fruit which yielded approximately 4,000,000 pounds of oil. Thus the production in 1940, which was the largest of record in the United States, was only about 1/40 of the quantity imported annually from 1934 to 1938. These figures on American production are estimates made from those of several individuals, for at present annual statistics for this crop are not reported by the United States Department of Agriculture.

Other countries which have made plantings of tung trees may come into production and help somewhat to relieve the existing situation, but now China is the principal source of imported tung oil. According to reports, it is not expected that South America and other countries interested in the industry will be producing tung oil in sufficient quantities to export much in the very near future. Therefore, the United States must continue to look to the Orient for the greater part of its supply, although American production is gradually increasing.

TUNG TREE IN CHINA

Information has been difficult to obtain as to the exact status of the tung industry in China. Several Chinese students in American universities have supplied some information, but, in all, the picture has been rather incomplete, so far as Americans consider data relative to some industry that is of vital importance to the economic structure of the country. However, recourse has been had to the published Inventory Lists of the Office of Foreign Plant Introduction of the United States Department of Agriculture and to a bulletin entitled "China Wood Oil" issued by the Department of Commerce. Much data have also been accumulated by Dr. H. A. Gardner of the National Paint, Varnish and Lacquer Association, Inc., and these have been available also in various publications issued by this association. Consequently, most information regarding the tung industry in China was taken from these publications, one by Dr. C. C. Chang, and a part from conversations with various Chinese who have visited Florida.

The Chinese have been familiar with tung oil for centuries. However, they apparently have given little attention to the culture of the tree, since it could be planted in waste places, such as ditch banks and hillsides, and in due time would produce fruit. No large cultivated orchards have been reported, but apparently some small ones have been maintained. The fruits are secured from these so-called cultivated trees and also from wild trees of both *Aleurites fordi* and *A. montana.*

The tree is said to thrive best in hilly countries where the altitude does not exceed 2,500 feet. However, this may be due to the fact that such hilly sections were the principal locations of plantings, as they would more than likely be the waste lands which could not be utilized for other intensive agricultural crops. This situation is quite different from that existing in the United States where trees have always thrived best on good soils and have never succeeded on those with low fertility, and in the wild without cultivation.

It has been reported from China that the trees can withstand a temperature of 4° F., but this doubtless refers to *fordi,* as *montana* will not survive at such a low temperature in the United States and has been killed to the ground by a sudden fall in temperature to 18° or 20° F. This agrees with the experience in the United States, except that temperatures of 26° and 28° F. have caused severe

damage to trees of all ages when not thoroughly dormant. Under such conditions young trees have been killed to the ground in some instances.

The tree in China is said to attain a height of 10 to 30 feet, with a trunk diameter of six to ten inches, and begins to bear in three to six years and to decline in ten years. It is said that the trees pass their maximum producing capacity at about ten years of age and are replaced by new plants in 12 to 14 years. Yields are said to be from 30 to 40 pounds of fruit per tree annually when at the height of production. One writer reports on a "3-year" tung, stating that the name is derived from the fact that the trees come into bearing in three years and usually bear about three crops, being cut down for firewood in their seventh year. This report states that the trees bear a light crop in their third year, increasing in production during the fourth, fifth and sixth years, and then rapidly decline in growth and yield and in oil content of the fruit, although production may be extended if the trees are planted on good soil. After the trees are cut down in their seventh year the land is allowed to lie fallow for several years in order for the soil fertility to be replenished, after which time it may be replanted to tung trees. This indicates that the idea is prevalent that the trees greatly impoverish the soil and that some time is required for the land to recover, and it would appear also that no fertilizers are used in the growing of tung. This has been substantiated by different Chinese students with whom contacts have been made on several occasions. These data, as reported for China, show less growth and yields than those obtained in the best producing areas in the United States where tung has been extensively planted.

Apparently, the method of planting in China is considerably different from that employed in the United States. Reports state that the Chinese farmer clears away a place in the waste land to plant the tree, digs a hole and fills in with compost or some other type of good organic material, and the trees are allowed to grow until the strongest one can be determined; then the weaklings are removed. No additional fertilization and cultivation are given the soil except to cut the vegetation from around the trees to eliminate competition. This may account for the reported short life of the tung tree in China as compared with the prospective age of the tree in the United States where the best practice is to prepare the land

before the trees are planted. There is probably some improvement taking place in China, or, at least, there are indications of this, as much of the information regarding cultural practices developed by the Florida Agricultural Experiment Station and other State and Federal agencies have been obtained by Chinese agricultural workers for the expressed purpose of testing these improved methods under conditions in China.

In China the methods of harvesting the fruit, shelling, grinding the kernel and extracting the oil are the old methods utilized for centuries and are quite different from the modern mechanical methods employed in the United States and certain other countries which have undertaken to establish a tung-oil industry. The Chinese practice is to allow the fruit to remain on the ground until the husks decay sufficiently to permit easy removal, when it is gathered and the seed removed. In some cases the fruit is gathered, placed in piles, and then covered with straw where it is allowed to remain and ferment, which accomplishes the desired purpose of getting the husks in such condition that they can be readily removed by hand. The husked seed are carried in baskets slung on poles to small mills where the oil is expressed by hand in a crude and unique type of wooden press.

After the seeds are cleaned of trash they are roasted and then ground in stone grinders propelled by hand power or operated by a domestic animal. The meal produced by grinding is mixed with water and steamed and then mixed with straw and placed in the crude wooden press. The press is fashioned out of a large log and pressure is provided with wooden wedges. It is made by hollowing out the log, leaving a narrow opening slit in one side through which the meal is placed in the press. This also allows for free passage of the oil and movement of the blocks and wedges as pressing proceeds. Blocks are placed in one end of this hollowed-out log and wedges are driven between these to exert pressure on the meal. As the mass is compressed another wedge is driven and this repeated until the pressing has been completed and the oil removed. The amount of oil that is wasted by this process must be rather large, as the residue doubtless contains a high oil content. It is said that the oil recovered is frequently mixed with dirt and other matter and must be strained. The oil is next placed in bamboo baskets previously lined with many layers of waterproofed paper, and covered with the same type of material.

The oil is purchased from the small mills by agents and transported in baskets by coolie labor to collection stations or river points from which it is transported to the coasts. By a settling process much of the solid impurities are eliminated. The oil itself is then separated into different grades, with the lightest in color being the best.

When the oil-laden junks arrive at distribution points, the baskets are unloaded by coolie labor where the oil is placed in tanks. Further settling takes place in these tanks and the oil is again separated into different grades, according to color and apparent purity. Formerly the oil was transported to America in oak barrels, but in later years tank steamers have been utilized for considerable quantities in bulk.

In the past there has been a great temptation to adulterate tung oil in China, according to reports. This was especially true when prices were high and the supply rather limited. However, reports indicate that there has been great reduction in adulteration during recent years. In 1929 the Chinese National Government put into effect an inspection service for tung oil for shipment to foreign destinations and established specifications based on foreign requirements.

Before the present war about 90% of the oil was assembled at Hankow, then the principal concentrating point for this product. The western provinces are the most important oil-producing areas and from these the oil is transported on the Yangtze River.

Since the Sino-Japanese war, various ports have been utilized. Much of the oil was routed to the Indo-China border, being carried by coolies or pack animals. The Burma road is now used to a limited extent. Since governmental control, the bulk of tung oil for export has been concentrated at Hong Kong. In 1939, 90.5% of the total export of China tung oil was shipped from Hong Kong, while only 4% was handled in the pre-war year of 1936. However, exports from Hong Kong have been cut off since Japan began the war against the United States and Great Britain. Exports have now been drastically curtailed from all ports.

TUNG TREE IN THE UNITED STATES

In 1905 the United States Department of Agriculture received tung seed from Consul General L. S. Wilcox, at Hankow, China,

for testing in the United States. These seed were planted in the Department's Plant Introduction Gardens at Chico, California, and seedlings were distributed from there to various cooperators. Several times during subsequent years the Department received seed from China; these, together with seed produced by the first trees grown, were planted, and many small nursery trees were sent to various parts of the country for testing wherever climatic conditions seemed to offer possibilities for tung tree growth.

Several trees went to Tallahassee, Florida, and in 1906 Mr. William H. Raynes planted five on his plantation nearby. One of these trees survived and lived until August, 1940, when it died following its removal from the right of way for a new highway. At the time the tree was removed and replanted it was about 35 feet tall and had a trunk circumference of 5.29 feet. Notes on the growth and behavior of the Raynes tree have been made available through the kindness of B. F. Williamson, of Gainesville, Florida. The tree bore three fruits in 1908 and continued to yield each year except when spring frosts destroyed the blooms and during the time it was recovering from damage caused by a fire which destroyed the plantation home shortly after Mr. Raynes died in 1914. The fruit produced in 1911 and 1912 were sent to the United States Department of Agriculture for examination. In 1913, 1095 fruits were forwarded to the Educational Bureau of the Paint Manufacturers' Association, Gibbsboro, New Jersey, and 2.2 gallons of oil were expressed, this being the first American-grown tung oil.

Plantings were made in the Tallahassee area with seed produced by the Raynes tree. One of these was planted in 1913 by Mr. Tennant Ronalds and consisted of four acres, but later it was increased to 40 acres.

One of the trees distributed by the U. S. Department of Agriculture from the early nursery at Chico, California, was planted by Mr. J. B. Wight at Cairo, Georgia. This tree is still living and has produced many crops of fruit. There are also several old tung trees in Baldwin County, Alabama, which were evidently planted during the early days of tung trials, as they are of large size.

The Texas Experiment Station planted two trees in 1907 and two in 1908. It is reported that the first two and one of the second pair lived until January, 1930, when they were killed by a temperature of −4 degrees F.

Early tests of the tung tree at the Florida Agricultural Experiment Station began in 1912, when ten trees were received from the United States Department of Agriculture and planted in the Horticultural Grounds. Some of the original trees died and were replaced in 1914. Certain ones of the first planted trees began to bear in 1916, and all after they had attained two to three years of age. All of these trees are still vigorous and in production except No. 5 which was killed by the extreme cold of November 15–17, 1940. The average annual yields per tree of air-dried hulled seed have been computed from the totals for the 19 years from 1922 to 1941. The first figure is the tree number; second, the average annual pounds of air-dried hulled seed produced; and the third, the amount of oil calculated in the seed: 1, 20.7, 7.1; 2, 39.0, 13.5; 3, 5.5, 1.9; 4, 17.2, 5.9; 5, 4.1, 1.4; 6, 33.5, 11.6; 7, 10.2, 3.5; 8, 24.4, 8.4; 9, 68.6, 23.7; and 10, 7.4, 2.5. Average for all ten trees: 23.0 pounds of seed and 7.9 pounds of oil for the 19 years.

Soon after 1920 interest began to be manifested in tung culture as a result of the ten trees growing on the Experiment Station Grounds, and a small orchard was planted near Gainesville, Florida, in 1923. In 1924–25 the American Paint and Varnish Manufacturers' Association planted an experimental orchard in another part of this area, but the land selected was too wet for tung trees and the test was not successful. Since these early trials various sized orchards have been planted in Florida, and there were in 1940 1,208,764 trees of all ages.[1]

Extensive plantings of tung have been made in Mississippi, and large orchards are to be found. These are located mostly in the southern parts where at one time there were large lumbering interests. In 1940 Mississippi had a total of 9,481,143 trees of bearing and non-bearing ages.

Large orchards have been planted in the southern part of Louisiana where there were formerly large lumbering operations, although there are not so many trees as are to be found in Mississippi. There were in 1940 1,758,819 trees of bearing and non-bearing ages.

In parts of southwestern Georgia there has been considerable interest in tung, and several orchards have been planted. In 1940 Georgia had 80,360 trees of bearing and non-bearing ages.

[1] Number of trees given for each state taken from the Preliminary Reports of the Sixteenth Census of the United States.

In southern Alabama near Citronelle, Fairhope and other locations a number of tung orchards have been planted. There were 102,972 trees of all ages in 1940 in the State.

Some interest has also been manifested in California, South Carolina and Texas. The 1940 Census reports 37,183 trees in Texas, 1,443 in California, and 560 in South Carolina.

HARVESTING

The methods employed in harvesting the fruit are quite simple. When the fruit becomes fully mature in autumn, it drops from the trees and is allowed to remain on the ground until thoroughly dry. It is picked up by hand and either sacked and placed in covered sheds to dry further, or is placed loose in well-ventilated buildings erected especially for the purpose. When stored in sacks the sacks are stacked in such a manner that air has free passage between them.

The buildings in which fruit is stored loose are so constructed that air has free access to the center as well as to outer parts. This is generally accomplished by erecting a crib-like structure, narrow at the bottom and flaring out at the top, with poultry netting nailed to the framework so as to leave the sides open for ventilation. Holes covered with wire netting are left in the floor to insure ventilation and also for ease in removing the fruit. These large outdoor bins are built at convenient locations in the orchard where the fruit can be placed in them as it is gathered. Unloading is accomplished with a gasoline engine-powered portable elevator similar to those used for handling small grain. The fruit is fed into the elevator through holes in the floor and the conveyor belt transports it into the truck body.

Where the fruit is stored in sacks the buildings are generally long open sheds of easy access, with the roof about six to eight feet high to allow convenient stacking. The sacks, tied in the orchard, are allowed to remain in these sheds until the time of milling the fruit, when they are loaded onto trucks and transported to processing plants. At the mills the fruit is dumped into large bins convenient to the conveyor belts running to the presses, and the empty sacks returned to the grower.

Great care must be exercised to prevent too high a moisture content of the fruit at the time of milling. This is the reason the fruit is allowed to become as dry as possible before it is picked from the

ground. It also explains why it is necessary to store the fruit in well ventilated, dry places which, in addition, insures further drying out of any excess moisture. The fruit should not contain too much moisture when it is to be shelled and run through the presses, for when too moist (more than 10% to 12% moisture) the seed contains an excess amount of water and gives trouble in the presses, and it is impossible to recover the oil in as high percentage as when the fruit is properly dried.

The first mill to be built in America, and in the world, for complete modern mechanical expressing of oil from tung seed, was erected in 1928 by the Alachua Tung Oil Company on their property near Gainesville, Florida. This plant initiated commercial production of tung oil in the United States, and the first tank car of American tung oil was shipped from Gainesville, Florida, in 1930, 17 years after the first oil was expressed from American grown tung fruits produced at Tallahassee, Florida. In addition to the mill at Gainesville, there is one other in Florida located at Brooker. There are mills also in Georgia, Alabama, Mississippi and Louisiana, at strategical locations which, in connection with the Florida plants, have ample capacity for processing the present production of tung fruit in the United States.

These plants contain modern equipment for decorticating the fruit, grinding the kernels and expressing the oil from these kernels. The decorticator, which is the machine that removes the hull or husk from the seed, consists of a rotary disk and huller. The seeds are delivered from these machines, after decortication, into conveyors in which they are transported to grinders and then to the presses. There the meal passes through the press, generally a screw type, where the oil is expressed under prssure. The oil is then passed through filters for the removal of solid matter and for clarifying, and it is then ready to be placed in storage tanks or tank cars for shipment. An average of about 16% (slightly higher in some fruits) of oil on the basis of the weight of the whole fruit is obtained by the expeller type presses. Thus the average amount of oil recovered is generally calculated to be about 320 to 350 pounds of oil per ton of whole fruit. The fruit, other than that produced by the mill owners, is either purchased from the growers or processed for them at a designated price per ton.

American produced tung oil is of very high and satisfactory qual-

ity. The oil is light golden or light amber in color and is nearly transparent after it has passed through the filters.

The tung oil cake, which is the residue left after the oil has been expelled, contains various percentages of oil, sometimes as much as 6%, which would be worth several dollars per ton of fruit at present prices if the oil could be recovered. This problem is being investigated in an effort to develop improved methods of expelling or extraction, together with the possibility of extracting the oil from the cake with solvents.

The hulls and pumace or cake are the principal by-products remaining after extracting the oil. Certain lots of press cake and hulls were analyzed by the Florida Station Chemist, and results showed that they had potential fertilizing value. The cake contained 6% moisture, 5.9% nitrogen, 1.97% phosphoric acid, and 1.41% potash; and the hulls showed 14.4% moisture, .74% nitrogen, .38% phosphoric acid, and 3.09% potash. All hulls and cake are applied to the soil in tung orchards as a part of the fertilizing program.

SOILS AND LOCATIONS

As stated earlier, tung has been planted on different types of many soil series in the South. This has given an opportunity to study growth and behavior of trees under various conditions. These soils vary all the way from deep sands to clays, and from soils low in organic matter to organic mucks. Drainage condition has been just as varied, some having little water drainage while others are well drained, with all possible combinations of conditions between these extremes.

In the United States the tree has grown better on soils with a friable clay subsoil which may be classed generally as sandy loams of the following series: Norfolk, Ruston, Orangeburg, Red Bay, Marlboro, Tifton, Faceful, Magnolia, Greenville, Gainesville, Arredondo and Ora. However, these must all be well drained so that the land will not remain wet over long periods of time and must be in a good state of fertility and kept so in order for tung to succeed on them. The land on which the orchard is located must have good air drainage and must not be in a cold area, otherwise losses from freezes after the trees start into growth are too great for profitable production.

The importance of location for a tung planting with reference to

cold cannot be over-emphasized. It is well known that certain areas are generally colder than others and that within the warmer areas there are locations which have poor air drainage. In these cold areas it is not advisable to make tung plantings, as loss from freezing temperatures while the trees are in bloom will occur too frequently. Such areas can be determined by the temperature record over a period of years and by the yields of any tung trees growing there for several years. However, there is a direct correlation between the relative dormancy, growth and vigor of the trees and cold damage. In general, it can be said that when tung trees are completely dormant they can stand relatively low temperatures without injury, though there is some variation between individual trees.

Cold damage to trees caused by freezing temperatures after trees have started into growth in spring is a very important factor in crop reduction. Such losses occur much too frequently in locations with poor air drainage within the warmer areas, and in the generally cold areas. The Experiment Station Farm at Gainesville, Florida, is located in a cold area, and from 1936 to 1941, inclusive, there have been four crop failures due to cold, while in a commercial orchard in a warmer area in the same county cold completely destroyed only one crop and reduced two others during the same period.

Location of the orchard, therefore, should be determined by taking into consideration several factors. The soil must be adapted to tung culture and situated in an area which is not cold, and the particular orchard site must have good air drainage. This is a difficult condition to describe in writing, but it is a well known fact that areas differ in their relative temperature records over a period of years, which must be taken into account when trees such as tung are being considered. It is recommended that anyone interested in and contemplating tung oil production make personal contacts with State and Federal station workers, and also growers in areas where tung culture is under way.

Various samples have been collected from different soils planted to tung in Florida, and pH determinations of these indicate that the soil should be moderately acid in reaction. There may be exceptions to these findings, but to date all of the heaviest bearing orchards have been those on well drained sandy loams having a pH below 7.

The most acid soils, usually, are those inadequately drained, and some of these have been planted without success. Frequently the trees make good growth for a while on these poorly drained soils, but sooner or later they begin to show signs of decline and soon become unthrifty if adequate water drainage is not provided. Under such conditions it is generally too expensive to provide adequate drainage for profitable tung culture.

DEFICIENCIES

Several nutritional disorders occur in the tung tree, some of which are known to be caused by a deficiency of zinc, manganese or iron, or a combination of these.

Zinc. Not long after the first commercial plantings of tung were made in Florida, a physiological disorder began to appear in certain localities. This was commonly called "bronzing" because of the bronzed color of leaves which developed with the disorder. The first symptom of bronzing is deformation of the terminal leaves, followed by a bronze color of the leaves, and as growth progresses there is shortening of the internodes and development of rosettes. The condition usually develops during summer but is most pronounced the latter part of the growing season. This results in a greatly weakened condition of the trees and is followed by severe winter killing of the twigs and branches, to such an extent that the trees so affected are greatly reduced in size. In cold weather badly bronzed trees may be killed outright or, at least, to the surface of the ground, and must be regrown if they are to be maintained as orchard trees. Experiments conducted by horticultural workers of the Florida Agricultural Experiment Station in 1930 showed that bronzing is caused by deficiency of zinc in the soil and that it can be corrected with zinc sulphate applied to the soil or to the trees as foliage spray.

The amount of zinc sulphate required is relatively small, and a less amount will be needed to maintain a normal condition of growth after the trouble has once been corrected. An ounce or two for each newly planted tree corrects the trouble the first year, but trees three or four years old, badly bronzed, require $\frac{1}{4}$ to $\frac{1}{2}$ pound per tree, spread around the tree on the surface of the soil. After the trouble has been corrected a maintenance program can be effected with about $\frac{1}{4}$ pound per tree applied to the soil every other

year, or $\frac{1}{8}$ pound applied each year with fertilizers, during the first four years. As the trees grow older it is necessary to increase the amount and to apply about $\frac{1}{4}$ pound each year or $\frac{1}{2}$ pound per tree every other year, and under some conditions of only slight bronzing this $\frac{1}{2}$ pound per tree application may hold the trouble in check if applied only once every third year.

Bronzing seems to be manifested to a greater degree in some areas than in others. Where the soil is deficient in zinc but of good fertility the trees may make good growth during the first year or two before severe bronzing is observed. However, even under such conditions growth is suppressed somewhat the first year and, as the trees grow older, they show increasing disorder, and after they come into bearing bronzing becomes severe unless zinc is applied.

There is another trouble reported as lime chlorosis which manifests symptoms somewhat similar to those of bronzing. It is thought now that this is probably one form of bronzing which may occur in soils over-limed or high in phosphatic limerock. Under some conditions of soils which contain large quantities of phosphatic rock and other liming materials, it may not be so easy to correct bronzing with soil applications, and therefore it may be necessary to apply zinc to the foliage.

Manganese. This disorder presents as its most typical symptom a chlorosis which has been designated as "frenching." Florida research workers in the Horticultural Department conducted experiments and revealed the fact that this disorder is caused by manganese deficiency which can be corrected with manganese sulphate applied either to the soil or to the tree as a foliage spray. Application along with fertilizers in spring holds frenching in check. Small amounts applied to the soil at the rate of about one to two pounds per tree generally is sufficient to eliminate this disorder when it occurs. If the trouble makes its appearance and is brought under control, it may not be necessary to make applications each year, except in severe cases.

Iron. As yet, this disorder has been noted only in localized areas in three orchards in Alachua County, Florida. It has been confined to definite areas in the affected orchards where groups of trees showed typical iron chlorosis in the leaves. In experiments conducted by Florida Agricultural Experiment Station workers it

was corrected with iron sulphate (C.P. and commercial form) applied either to the soil about the tree or as a foliage spray.

INSECTS AND DISEASES

At present there are no insects or fungus diseases of tung trees causing any particular concern. There are a few which have made their appearance but they have not caused much trouble and have not occasioned serious losses.

Nematodes have caused some trouble on nursery stock when the trees were planted on lands heavily infested with them. However, experimental plantings of heavily infested nursery stock on the Florida Experiment Station Farm along with stock free of root-knot grew out of the infestation and, when removed a few years later, were free of root-knot and made satisfactory growth. Therefore, nematodes may cause severe damage to young trees in the nursery and seriously regard their growth during the first year or two, but when the trees are transplanted to the orchard the root-knot disappears.

There have been three scale insects reported on tung trees, none of which has proved serious to date. They are the ivy scale (*Aspidiotus hederae* (Vall.)), latania scale (*Aspidiotus lataniae* (Siga)) and the cottony cushion scale (*Icerya purchasi* (Mase)). If necessary, the first two can be controlled with a dormant spray of lime sulphur or oil. The cottony cushion scale can be controlled biologically with *Vedalia* lady bird beetle released in the orchard when infestations are sufficiently severe to warrant control measures.

Thread blight (*Corticium stevensii* (Burt)) has produced some injury to an occasional tree in some orchards, and when severe causes a dying back of the branches. One bacterial spot (*Bacterium aleuritidis* (McCulloch and Demaree)) of tung leaves has been described, but no serious damage caused by it has been reported.

Mushroom root-rot (*Clitocybe tabescens* (Scop.) (Bres.)) has been the most serious disease attacking the tung tree. It is not common and generally occurs only where oaks and other native host trees have been cleared away to permit planting tung trees.

PROPAGATION

In the first manifestation of interest in commercial production of tung in America, the thought among research workers and growers

alike was that the only way to be sure of obtaining prolific trees was through budding and grafting, similar to that practiced with other tree fruits and nuts. Consequently, attempts were made during the early days of the industry to propagate trees asexually. Two methods were undertaken, one by rooting cuttings and the other by budding, and later grafting was tested. Investigations into the merits of budding and grafting were started at the Florida Agricultural Experiment Station in 1924, and in grafting shortly thereafter.

Several problems soon developed in connection with budding that had not been encountered with other orchard trees. Generally, it was not so difficult to obtain success with buds inserted by the common patch bud method, but it was not always easy to force the buds into growth after a satisfactory "take." Then, after it was possible to get one started, it did not necessarily follow that the tree would grow as well as did the seedlings from the same tree from which the buds were taken. Just why this should be true is not definitely known but possibly there may be a stock difference. Indications are that one tree may produce a seedling which will grow a bud to better advantage than will another. Whether this is true should be revealed by experiments which have been set up by the United States Department of Agriculture, Bureau of Plant Industry, Tung Laboratories.

There are other factors which have operated to mitigate the efforts at vegetative propagation of tung trees. The most important of these is that a large percentage of seedlings grown from seed of certain prolific trees will be like the parent in this respect. From an experimental planting made January, 1930, on the Florida Experiment Station grounds (comprising budded Numbers 2 and 9 and seedlings of 2 and 9), some interesting data have been obtained. The seedlings have produced a higher yield per tree than have the buds, and they have likewise made a somewhat more vigorous growth. In more than 51% of the trees, the individual seedlings resemble the parent in respect to vigor, growth, flower and fruit characteristics, and prolificness. In about 75% of the trees the difference is only slight in one or more characters such as shape of fruit or habit of growth. However, in all but a small percentage, less than ten, the trees appear to be just as vigorous and as productive as the parent trees. Since this experiment has been con-

ducted with over 100 trees of each, budded and seedlings, the results are highly significant. In 1940 the average yield of fruit per tree for seedlings of 2 and 9, respectively, amounted to 78.6 and 73.4 pounds, while the budded trees of 2 and 9 produced 30.0 and 50.0 pounds, respectively. A block nearby made up of miscellaneous seedlings set in 1923 and given like care and attention yielded an average of 57.7 pounds per tree.

At first seedling stock was grown from miscellaneous seed without any special reference to the characteristics of the parent trees. Later, however, most growers attempted to make selections of seed for planting from prolific trees based on one or more records. On the basis of experimental results, growers, in general, have not hesitated to plant large acreages of seedling trees grown from seed selected from trees that are vigorous and productive.

The methods of budding first tested by the Florida Station were patch and shield, and later chip budding was tried with apparent success. The patch proved the most satisfactory and was used exclusively after the initial trials. Both cleft and bark grafting were tested in these early trials and later tongue grafting was included. The bark and cleft were tested as methods of top-working large trees, and also in working old seedlings which had become too large to bud or tongue-graft. The tongue-grafts were employed in some experiments in piece root grafting and in working small seedlings. All these methods gave satisfactory results so far as uniting of scion and stock were concerned except in the shield bud which did not prove successful. However, the resulting tops have not made growth equal to that obtained with seedlings of the same clone, except in a few instances, and yields have been less.

In 1938 when the Bureau of Plant Industry initiated tung investigations and opened the field laboratories, one of the problems undertaken concerned methods of tung tree propagation. Consequently, the workers in these laboratories have done a great amount of work along this line during the past three years. They have evolved a method of making and inserting a modified shield bud which is reported to be apparently successful.

In all methods of budding the buds are held in place with some acceptable tying material. Regardless of the material used, it is necessary to wrap the bud in place in such a manner that moisture and air cannot enter the cut surface and come in contact with the cambiums of the bud and stock.

CULTURE

In the culture of the tung orchard it is necessary to give attention to the soil and location of the orchard to provide adequate water and air drainage and to maintenance of soil fertility. The orchard is laid out according to the particular desires of the planter. The three principal planting plans utilized are the square, rectangle and contour.

Since most present acreage in tung is planted with seedling trees, two methods have been employed in starting orchards. One is transplanting of seedling trees grown for a year in the nursery and the other is spot planting of seed in permanent location in the orchard. The first method was used exclusively by early planters, but in later years many have employed spot planting, and many thousands of acres have been started in this manner. Just which of these is the most satisfactory must be determined by research, but apparently the one to use is largely a matter of personal preference. It would seem, however, that it would require less labor to maintain a nursery and then transplant the stock in the orchard than it would to grow trees in place. When seeds are spot-planted the tree location must be marked with a stake so that the young seedlings may be protected from the time they come through the ground until they attain a height of 12 to 18 inches. Three or four seeds are planted in each hill, and after several months of growth all but the strongest seedling are removed. During the growing season much labor is required in keeping down weed growth to eliminate competition. This is quite a job during most years, and it is especially difficult to keep the area around young seedlings clean of vegetation during periods of excessive rains.

Transplanting of tung trees is not greatly different from that of other fruit and nut trees. Generally, they are rather easily transplanted, and a high percentage live with reasonable care in protection of the roots to prevent drying, and if the trees are set properly after having been cut back to 8 to 12 inches.

Planting distances have been much discussed. Some advocate planting 15 feet in rows 30 feet apart, others 20 by 30 feet, some 25 by 25 feet, and 30 by 30 feet, and various distances between these. There is a tendency now, however, for trees to be set farther apart, and some who formerly set 15 by 30 feet are now planting 20 by 30. The 30 by 30 foot plan is being used to some extent and at present

seems to be about the minimum distance that trees should stand, as it permits the trees to attain larger size without crowding and thus insures greater bearing surface. However, when the size of old trees on the Florida Experiment Station grounds is considered, this would still seem rather close. As information on planting distances is developed, methods of thinning will be worked out which will enable growers to reduce the number of trees per acre if necessary to maintain profitable yields on old trees.

After the trees are transplanted they force several branches from the cut back stub. Some growers allow all these branches to develop, while others train to a single stem, these two types being commonly designated, respectively, as multiple and single trunk trees. Regarding the merits of these two systems, some growers are just as insistent that the multiple trunk is best as others are that the single trunk is the ideal method of training. Time and experimentation will determine the one which is best to give the greatest yield.

In growing young trees there is sometimes difficulty in getting them to branch properly and at the desired height. Height of natural branching is to a large extent determined by inheritance. Yet, in growing trees in the orchard or nursery from seed planted in place, if the trees do not branch naturally the first year there is danger of their developing a condition of branching which is undesirable when growth starts the next year. This condition is generally referred to as "cart-wheel" because of resemblance to the hub of a cart with branches coming out from the central bud at the terminal, arranged like the spokes of a wheel. When spot-planted trees do not attain sufficient height the first growing season to branch naturally it is better to cut the trees back to a six to eight inch stub and regrow the top. Under such conditions, the original top, if allowed to remain unpruned, will, in all probability, develop the cart wheel, while the cut back tree will generally grow vigorously and branch normally. In such instances the branches can be properly spaced without much difficulty, while the unbranched top at the end of the season presents an almost impossible problem in forcing well-placed branches. As the trees grow older, those which are poorly branched, due to cart wheels or other undesired types, evidence much splitting when heavy crops of fruit are produced.

Where the orchard is started with transplanted nursery stock and

trees are grown as multiple trunks, this cart wheel condition is apparently not so evident. This seems to be accounted for in the fact that, when several branches grow together from the same trunk, there is an interlocking of the young branches which seems to afford some support to all branches. There are definite cart wheel types of branching developed on the different branches under the multiple system of training when the trees do not make proper growth. However, they are not so noticeable, since there are several branches on which the cart wheels do not stand out prominently, but, if there were only one single stem and that had developed a cart wheel type of branching, the condition would be quite noticeable.

Very little pruning is practiced except on young trees to train to a single stem where this type is desired. In older trees all that is required is to remove dead branches and those which interfere with development of others. In locations subject to severe cold damage there are varying amounts of dead wood to be cut out, following freezes similar to that experienced in the Gainesville, Florida, area in November, 1940. However, such freezes are rare; that was the coldest November of record at Gainesville.

One type of pruning is employed by growers to induce branching at desired locations. This consists in notching the trunk or branch just above the bud to be forced. This generally forces into growth the bud below the notch and enables the orchardist to develop any desired system of branching. The dormant buds on the stem hardly ever force under normal conditions, but in most cases a slit through the bark into the cambium just above the bud induces that bud to force, especially if the terminal bud is removed.

Maintenance of soil fertility is of great importance in connection with successful tung culture. During the first years young trees in the orchard do not require much fertilizer, but it is necessary to apply what they do need to insure satisfactory growth. The amount to apply depends somewhat on fertility of the soil and on the amount and kinds of cover-crops returned to the soil. However, about ½ to ¾ of a pound per tree of a mixture containing nitrogen, phosphoric acid and potash in about 5%, 7% and 5% ratio, respectively, is generally sufficient. Where poor growth is made by young trees it is advisable to step up the nitrogen to 6% or 7% and, in some instances, apply in July about ¼ pound per tree of some nitrogenous material, such as sulphate of ammonia or nitrate of

soda. As the trees grow older they should receive about the same mixture, with the amounts increased annually at the rate of ½ to one pound for each additional year. This permits application of about five pounds per tree in a five-year-old orchard and about eight to ten pounds for ten-year-old trees.

On soils with a friable clay subsoil the fertilizer can all be applied once in spring about the time or just before growth is manifested. This generally is the last of February or first part of March. However, in some soils with little clay it seems advisable to apply one-half the fertilizer in spring and half during summer. Some growers apply the regular fertilizer in spring and supplement with nitrogenous material in summer.

Regardless of the commercial fertilizer used, growers make a practice of applying on the orchard the hulls and cake returned from the mill. As previously stated, the hulls and cake are by-products of the fruit after the oil has been expelled from the seed.

Owing to the fact that the sandy soils of the South are low in organic matter, it is necessary to grow and return cover-crops to the land for best results with tung. There are several green manure crops which can be utilized for this purpose, and since legumes fix and return atmospheric nitrogen, a suitable cover-crop of this kind is the most satisfactory. The fertilizers apparently do not need to contain as much nitrogen as where such crops are not grown and returned to the soil.

The first years after starting the tung orchard is an excellent period during which to return large amounts of organic materials to the soil in green manuring crops. During this period of orchard development the trees are small, and the main area cultivated during summer is a narrow strip on each side of the tree rows. This permits growing a heavy crop of some good summer legume which can be disked into the land in late summer. Crotalarias are among the best for summer. One of the best is *C. spectabilis,* but since it is toxic to livestock when eaten by them it is not recommended if animals are allowed to graze in the orchard. *C. intermedia,* however, is not toxic and is a good cover which makes satisfactory growth on tung lands, as will beggar weed which gives good results in a soil maintenance program. These cover-crops produce seed and volunteer each year when handled properly and when the land is cultivated at the right time. Summer cover-crops which must

be planted each year include velvet beans, cowpeas and Alyce clover. However, after the trees attain large size and shade most of the land, it is difficult for a cover-crop to make satisfactory growth during the growing season under such shaded conditions.

Winter cover-crops are important in tung orchards and several can be grown satisfactorily on lands which have a considerable amount of clay. Soils with little clay are generally not very well suited to these green manure crops, although they make better growth after several heavy crops of summer legumes have been returned to the land. Vetches and Austrian peas are among the most commonly planted and give excellent results because they grow when the trees are bare of foliage, and during the dormant season there is no competition with the trees for moisture in the soil. They can be conveniently disked into the soil at the time the spring fertilizers are worked in.

Lupinus angustifolius is proving to be a valuable cover-crop during winter in the general area where tung is being planted. There is every reason to believe that it will also prove a valuable cover-crop for tung orchards along with vetches and Austrian peas.

Several vetches grow satisfactorily and produce adequate tonnage of green material in maintaining fertility of the soil. Hairy vetch is one of the most commonly planted, but the seed must be sown each year under most southern conditions. Common vetch also has given considerable promise throughout the South, and under some conditions it reseeds. Augusta vetch (*Vicia angustifolia*) has proven itself valuable as a cover-crop in orchards of northern Florida and of the Florida Station at Gainesville. Under suitable conditions it makes heavy growth and produces adequate seed for a volunteer crop of plants each year. It is a valuable grazing legume also and works into the livestock program in the tung orchard and can be disked into the land in spring the same as other vetches.

Austrian peas are probably the most generally planted of all winter legumes. The seed must be planted each fall, but they are readily obtainable at a moderate price. Under favorable conditions they return a heavy tonnage of green material to the soil and generally are ready for disking at a somewhat earlier date than the vetches.

All winter legumes mentioned must be fertilized under normal conditions to insure a profitable growth of tops. The fertilizers

usually consist of from 300 to 500 pounds of superphosphate or basic slag per acre, applied just before or at the time the seed are disked in during early autumn. It is also good practice to apply from 75 to 100 pounds per acre of muriate or sulphate of potash along with the phosphatic materials. The winter legume seed must be inoculated with their respective bacteria for suitable growth on lands which have not previously grown successful crops of the particular species being planted.

Cultivation of the tung orchard is not very intensive. During the first two or three years the tree rows should be kept cultivated with a disk harrow to prevent growth of weeds and grasses which compete with the young trees for water and plant foods. The entire area between the tree rows should be cultivated with a disk in spring and again in late summer or early fall. During dry periods the land should be disked to keep down vegetation or the growth kept mowed to conserve the soil moisture. After the trees attain three or four years of age, cultivation consists of disking the land completely between the tree rows in spring, and again in fall when planting the winter cover-crop and getting ready for harvesting, except as it may be necessary to check growth of vegetation to conserve moisture during droughts in the growing season.

VARIETIES

Up to the present there has not been any great attempt to introduce named tung varieties. Tree No. 2 of the original ten trees on the Florida Experiment Station grounds has come to be known generally as the Florida. This is a cluster type and has been the source, directly or indirectly, of considerable acreage in tung in the United States.

Tree No. 9 has been utilized in many plantings and has been so designated, and, while it has not been given a name, it can be considered as a variety and will doubtless be honored with an acceptable name at some future date. It has certainly had an excellent record in point of production and has the ability of passing on to its progeny the vigor and prolificness that make it stand out prominently among tung varieties.

Workers in the United States Department of Agriculture in tung investigations have selected a large number of clones with which they are conducting experiments. These have been chosen as

foundation stock with which to carry on their breeding and propagation work.

The tung industry is still in the seedling stage, and it will continue so until methods of asexual propagation are in general use. Especially is this true in face of the fact that it is possible to make selections of certain individual trees which will pass on their prolific characteristics to a large percentage of their progeny, as is true with Trees 2 and 9 of the Florida Station.

With the advent of successful asexual propagation there will doubtless be numerous varieties introduced, and probably this will be done in many cases on the basis of an individual tree record with no orchard tests to determine what it will do under field conditions. The value of this kind of data is doubtful, as it is well known that the record of one individual tree cannot be taken as the final criterion of what its progeny will ultimately do when planted out under orchard conditions. Many have been the failures of varieties of fruits and nuts introduced on just such a basis. Therefore, it cannot be too strongly emphasized that, before a grower puts too much faith in an individual tree, its merits must be first determined in the orchard. This is not a difficult matter, as ten or more acres can be planted and managed the same as the other part of the orchard, and it may thus be learned how the variety will perform under field conditions. Such tests will make it possible to develop information on which to base future plantings.

The tung industry to date has been developed and expanded rather rapidly over a wide area in the South. The pioneer spirit of the American people has again been emphasized, for those who have made these early tung plantings are truly pioneers, just as others have been who paved the way for many horticultural industries in the United States.

RESEARCH

The first research with tung was conducted by the United States Department of Agriculture when it secured seed from China in 1905 and distributed seedlings in 1906 to experiment stations and various individuals where there seemed to be some possibility of the trees' surviving. Subsequently the Department of Agriculture grew and distributed additional tung seedlings for widespread testing throughout warmer sections of the United States.

Research with tung at the Florida Experiment Station was started in 1912 when the first trees were received from the United States Department of Agriculture Introduction Gardens at Chico, California. These were the first of the original ten trees planted on the Station grounds, but later, in 1914, other trees were planted to replace some of the first which had died. There were no further experimental plantings until 1922 when a test block of about four acres was set with stock grown from miscellaneous seed. In 1923, 1924 and 1925 additional small blocks were set to tung trees for testing, and in 1930 an experiment was set up to compare budded and seedling trees. Experiments conducted with tung have included fertilizers, cover-crops, micro-elements, propagation, pruning, training, flowering and fruiting habits, fruit characteristics, oil content of the seed and its variation.

Results of research at the Florida Station have been mentioned at various places throughout this article, and literature references to it are given in the bibliography.

However, these investigations have supplied much valuable information relative to the solution of several important tung problems. Some of these problems were of such vital importance to this young horticultural industry that they seriously threatened its development. The nutritional disorder known as "bronzing" was one of these and it would have greatly retarded expansion of tung plantings if research had not developed the fact that it is caused by zinc deficiency and that it can be controlled with zinc sulphate applied either to the soil or to the foliage as a spray. Tree growth and fruiting characteristics have been studied in connection with their effects on production with the result that more prolific types are now available for planting. Much data are now available in regard to soils adapted to tung culture and also on the general nutritional requirements of the tree.

The several state experiment stations in the area where tung trees have been extensively planted are conducting research along various lines with this new horticultural crop. Their investigations cover a wide field and many problems are being worked on. Their publications are listed in the bibliography.

A great amount of research work is being conducted by the United States Department of Agriculture through its tung laboratories at strategic locations throughout the South where tung has

been planted. These laboratories are located at the following places: Florida Agricultural Experiment Station, Gainesville, Florida; Cairo, Georgia; Alabama Gulf Coast Sub-Station, Fairhope, Alabama; and Bogalusa, Louisiana. The tung investigations by the Department were started in 1938 and have been expanded considerably since that time. In Florida, as well as other states, these laboratories carry a considerable amount of work in cooperation with the Experiment Station. Papers published are given in the bibliography.

The Bureau of Agricultural Chemistry and Engineering, United States Department of Agriculture, is conducting chemical research with the oil and by-products. Much work is also being done on solvent extraction of oil. These investigations are being carried through laboratories established in 1938 and located at Gainesville, Florida, and Bogalusa, Louisiana.

TUNG IN COUNTRIES OTHER THAN THE UNITED STATES AND CHINA

Reports are to the effect that *Aleurites fordi* and other species of *Aleurites* are being tested in many countries which have climates that offer possibilities for growing tung trees. According to this information, it would seem that there has been some progress in certain countries. In some, thousands of acres have been planted, mostly of seedling stocks, some of which were grown from seed purchased from American growers.

Argentina, Brazil, Paraguay and possibly other countries in South America have made extensive plantings. Some of these have now been planted long enough for the trees to bear fruit in quantity. Information from Argentina is to the effect that in 1940 about 500,000 pounds of oil was produced in that land. Probably many plantings in South American countries have been made with seed produced in the United States.

Plantings of tung have been made in various countries over the world in addition to those in South America. Many are of large size, others are small. The trees in many instances came from seed produced in American orchards, according to reports. Burma has planted large acreages of *Aleurites fordi* and some *A. montana,* and these will furnish an indication as to what these species will do in that country. Considerable interest has been manifested in Java,

and prospective planters have visited the United States and looked into the methods of growing tung in Florida and other southern states. Some reports indicate that *A. montana* is more promising than *A. fordi*. In Ceylon there has been some interest, but to what extent test plantings have been made is not known. In Australia considerable acreage has been planted to tung, and reports are to the effect that some are promising. Part of these plantings should be old enough at present to indicate what might be expected in fruit production, but no late definite reports are available. Many acres have been planted to tung in New Zealand, and there seems to be considerable interest, according to reports. In Russia large orchards of tung have been planted and several publications have been issued by the Russian Government. Many visits have been made to the United States by Russian Governmental officials who have discussed tung at length, and much seed was purchased from American growers. Plantings have also been made in South Africa and it is understood that some of these are promising. Tung plantings of *A. fordi* apparently have not given much promise in Haiti, Puerto Rico, Jamaica, British Honduras and other tropical countries, but reports indicate that *A. montana, A. trisperma* and *A. cordata* might be more worthy of trial, since they are more tropical in their requirements.

SUMMARY

The tung tree (*Aleurites fordi*) was introduced into the United States in 1905 from China by the Division of Foreign Plant Introduction, Bureau of Plant Industry, United States Department of Agriculture. It has been most extensively planted in the United States in Florida, Mississippi and Louisiana, and, to a less extent, in Georgia, Alabama, Texas, and South Carolina. Some interest has been shown also in California.

According to the 1940 Census there were 12,671,344 tung trees of all ages in the United States in 1939. Of these, 4,114,555 were of bearing age, and 8,556,789 of non-bearing age.

The 1940 American production was estimated at about 4,000,000 pounds of refined oil. The 1941 crop will probably be somewhat less due to cold damage in November, 1940, in certain areas.

The oil, which is obtained from the seed, is the principal product of the tung tree. It is one of the best drying oils known and is used in large quantities in the manufacture of certain types of varnishes,

paints and enamels; also in the electrical industry for manufacturing certain insulating compounds used in dynamos, cables and wire coatings. Tung oil is of great importance in the manufacture of oil cloth and linoleum and in waterproofing various fabrics and for many other purposes.

Tung oil has been imported from China for a number of years. In 1937, 174,885,000 pounds were received for all purposes. Importation now is drastically curtailed due to the war.

Tung trees grow best on well drained loamy soils. Cover-crops of legumes are profitable, to be returned to the soil in the fertility maintenance program. In most areas both winter and summer legumes can be grown successfully.

Commercial fertilizers must be applied to give best results in tree growth and fruit production. They should contain about 5%, 7% and 5%, respectively, of nitrogen, phosphoric acid and potash. The by-products of tung fruit after the oil is expressed consist of hulls and cake. These should be returned to the orchard and broadcast over the land, as they have fertilizing value. This practice is followed by most growers.

Cultivation consists of disking the land in spring and fall. With young plantings the tree rows are also disked several times during the growing season.

Cold damage is generally caused by killing of flower buds when the temperature goes to freezing or below after the trees start into growth. When completely dormant the trees endure relatively low temperatures without apparent damage.

Physiological disorders caused by deficiency of zinc, manganese and iron have been determined. Bronzing is caused by zinc deficiency, frenching by manganese deficiency, while iron deficiency is manifested by chlorosis and a definite type of pattern in the leaf. Bronzing has been the most serious physiological disorder and is controlled with zinc sulphate applied either to the soil about the tree or to the leaves in a spray. The soil application is practiced commercially.

Tung trees are propagated mostly by seed selected from prolific types bearing fruit with relatively high oil content in its seed. Vegetative propagation is being experimented with and plantings of budded trees have increased in a small way during the last few

years. However, to date the vast plantings have been made to a large extent with seedling stock.

Orchards are started either by transplanting nursery stock or by spot-planting the seed in place.

A bushel of air-dried whole fruit weighs approximately 30.75 pounds, and the same quantity of air-dried hulled seed weighs about 42 pounds.

The percentage of oil in the whole fruit varies from about 15% to as high as 25%, but the average to be considered for milling purposes ranges rather close to 16%. The average oil in the seed is about 33.33%.

In China the oil is expelled from the seed in crude wooden presses, but in the United States this is accomplished in modern mechanized mills. Expressing plants have been erected in Florida, Georgia, Alabama, Mississippi and Louisiana.

American oil is of high quality and is light golden or light amber in color.

The fruit matures in late summer or early fall and then drops to the ground. When fully dry it is picked up and placed in dry storage until it is transported to the mills. The oil is expelled from the seed by pressure. From the press the oil is passed through filters for clarification.

The other species of *Aleurites* are experimented with in the United States, namely, *A. montana, A. moluccana, A. cordata* and *A. trisperma.* These are all more tropical in their requirements than *A. fordi* and must be confined to the warmer sections.

Aleurites fordi and other species are being tested in many parts of the world outside the United States where climatic conditions seem to offer cultural possibilities.

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THE RÔLE OF ASCORBIC ACID IN PLANT NUTRITION

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Since the isolation and identification of vitamin C (1) in 1932 there has been much investigation regarding the rôle of this physiologically important substance. The term "ascorbic acid" for the vitamin was first proposed (2) in reference to its anti-scorbutic properties. Chemically the vitamin is referred to as *l*-ascorbic acid to distinguish it from its two isomerides, *d*-arabo-ascorbic acid and *l*-arabo-ascorbic acid. Of the three isomerides, *l*-ascorbic-acid is the only one which has the full anti-scorbutic potency of the natural vitamin, *l*-arabo-ascorbic acid is quite inactive, and *d*-arabo-ascorbic has about one-twentieth of the activity of the natural vitamin. *L*-ascorbic acid can be reversibly oxidized to *d*-ascorbic acid, which form is usually referred to as dehydroascorbic acid. Only the first stage of oxidation is reversible and takes place under mild conditions of oxidation; under other conditions oxidation proceeds to the second or irreversible stage. The physiological action of the vitamin is presumably due largely to its peculiar reducing activity, associated possibly with the characteristic "endiol" group

$$-(HO)C=C(OH)-.$$

The precise rôle or functions of ascorbic acid in plant nutrition is not known. King (3) says: "from the close relationship between growth and vitamin C content it is reasonable to conclude that the vitamin has an essential rôle in the over-all growth processes of animals and plants." Investigations (4) reveal a close association of the vitamin with the Golgi apparatus and mitochondria in animal tissue, and point out the selective retention of the vitamin in certain parts of the cell. No comparable work of this nature has been reported in plant physiology.

It has been well established that dry seeds contain very little ascorbic acid or dehydroascorbic acid (5), but when germinated, ascorbic acid appears within a fairly short time. Considerable research indicates that the vitamin is in a great range of plants, algae and bacteria not excepted.

Davis and Hudson (6) report that in low concentrations, 1 : 100,-

000, the vitamin has a stimulating effect on germinating seeds, higher concentrations retarding development. Povolotskaya (7) found that legumes form more ascorbic acid than do cereals. This difference seems to be associated with the large cotyledons of the legumes. Von Hausen (8) found that the source of ascorbic acid in young pea plants is in the cotyledons. In her work von Hausen showed that the ascorbic acid contained in the cotyledons exerts an important influence on the development of young pea seedlings. Removing the cotyledons reduces the ascorbic acid content to a low level. Plants so treated are almost checked in growth. Addition of ascorbic acid to the medium results in a striking effect on development of the plants with the cotyledons removed, the dry weights of the treated plants being twice that of the controls. Addition of ascorbic acid to the medium after blooming is without effect on plant growth. Further work (9) has shown that formation of the vitamin increases with nitrate increase up to an optimum concentration of .05% to .10% of KNO_3. The work of Reid (10) shows that the percentage of ascorbic acid in the tissues increases up to the time of blooming, followed by a continuous decrease up to the time of ripening. Highest concentration is in the leaf, leaf buds and blossoms, respectively. Lowest concentration is in the roots. These areas of high ascorbic acid concentration are also areas of greatest cellular activity, *i.e.,* mesophyll of leaf, young ovary, meristem tissue, leaf and blossom buds. Various workers (11–14) indicate that light has considarable effect on the accumulation of ascorbic acid during germination and early stages of development. Plants grown with low light intensity and low nutrient level are lower in ascorbic acid content than plants grown under more optimum conditions. Addition of glucose to seedlings low in carbohydrate reserve caused an increase in ascorbic acid content. The most recent work on the effect of light on ascorbic acid content has been the most pertinent. In this investigation Murphy (15) points out that other workers have drawn their conclusions indirectly from data intended to determine the effect of other factors. Murphy found that the "sunny" side of an apple contains larger amounts of the vitamin than the "shady" side.

Growing plant embryos isolated from their seed food supply by removing the cotyledons before germination, Bonner (16) has shown that the embryos of different varieties of peas differ widely in their ability to synthesize ascorbic acid from sucrose.

Experiments (17) on carbohydrate assimilation before and after addition of ascorbic acid supports the theory (18) that the vitamin plays an important rôle in photosynthetic formation of formaldehyde.

RELATIONSHIPS TO ENZYMES

Szent-Györgi (19) observed that plants and fruits can be divided into two main groups: those which show discoloration on injury, apple, pineapple, banana, potato; and those which do not, lemon, orange and cabbage. Szent-Györgi observed that "most vegetable tissues which do not have the phenoloxidase system and which do not discolor on injury contain a highly active peroxidase and very little catalase. Further these tissues contain in relatively high concentration, a substance which is characterized by its strong reducing properties. . . . This has been named hexuronic acid. . . . The latest studies on cabbage leaves have brought out the fact that in this plant hexuronic acid plays a central role in normal respiration." This hexuronic acid has since been identified as vitamin C and named "ascorbic acid." Here Szent-Györgi described the essential rôle of ascorbic acid in plant respiration three years before identification of the vitamin.

The theory that ascorbic acid serves as a respiratory catalyst is further supported by work (20) which shows that only the first oxidation of ascorbic acid is physiologically reversible, *i.e.,* ascorbic acid $\rightleftharpoons$ dehydroascorbic acid. It was found (21) that even minute traces of copper catalyze oxidation of the vitamin. Mack and Kertesz (22) have shown that this catalytic effect is considerably increased by addition of small amounts of iron. Stotz (23) attributes the catalytic activity of squash oxidase on the oxidation of ascorbic acid to a copper-protein complex in which the copper serves as an active catalyst. This catalyst found in many plants has been frequently called "ascorbic acid oxidase." Snow (24) has called attention to the fact that there are other substances than vitamin C which are oxidized by this so-called ascorbic acid oxidase. Snow found that this oxidase would also oxidize reductone, glutathione and cysteine. In view of this the name "ascorbic acid oxidase" should be discontinued. Barron *et al.* (25) point out that biological fluids may be divided into two groups, those possessing inhibitory mechanisms protecting the ascorbic acid from oxidation and those without them. In the first group there are appreciable quantities of the

vitamin where it is protected by the action of such substances as glutathione and proteins. In the second group ascorbic acid is oxidized by a number of catalysts. This view is subject to criticism since some work (26, 27, 28) has shown that in certain plants, such as cabbage and carrot, there is an increase in the ascorbic acid value after boiling. This increase is due to the release of ascorbic acid from a combined form, a protein-ascorbic acid complex, soluble in cold water. Combined ascorbic acid is found only in certain plants, in which form it is not detectable by the usual chemical methods. Pal and Guha (29) propose the term "ascorbigen" for the ascorbic acid held in the combined form in plant tissues. The suggestion that the combined vitamin is held in the form of an ester has received no support.

RELATIONSHIPS TO CHLOROPHYLL AND CAROTENOIDS

Usually associated with ascorbic acid are chlorophyll and carotenoids. Parts of the plant rich in chlorophyll or carotenoids are almost always rich in ascorbic acid. In analyses of 60 different fruits, Giroud (30) showed that those containing carotenoids were by far the richest in ascorbic acid. While cotyledons contain very little ascorbic acid there is a rapid increase in the relative concentration of the vitamin in these organs soon after germination. High chlorophyll content is always accompanied by high ascorbic acid content and low chlorophyll content (flower parts excepted) by low ascorbic acid content. Carotenoid pigments are accompanied by a high concentration of the vitamin, the carrot being a notable exception; also there are many exceptions of non-pigmented tissues, particularly sprouts which are rich in ascorbic acid. The presence of chlorophyll is known to protect ascorbic acid from oxidation by oxygen; carotene, however, does not protect the vitamin from oxidation by oxygen (31).

EFFECT OF NUTRIENTS ON ASCORBIC ACID CONTENT

The maximum concentration of ascorbic acid at which plants in water cultures can grow is less than 1:5000. Concentrations of 1:5000 or more are lethal (32). Havas found that a concentration of 1:10,000 was optimum for growth of tomatoes. Tomatoes treated with a 1:10,000 concentration showed no acceleration of growth or flowering and had a smaller number of fruits but with

20% greater total weight. Studying the effect of fertilizers on the anti-scorbutic potency of apples, Potter *et al.* (33) determined from biological assays that trees receiving a complete application of fertilizer, namely, nitrogen, potassium and phosphorus, are a a richer source of ascorbic acid. At variance with these results, is the claim (34) that the vitamin C potency in apples is greater in those of low nitrogen supply and ascorbic acid metabolism. Ott (35) found that potatoes show an increase in ascorbic acid content with nitrogen and phosphorus fertilization and a decrease with potassium and calcium oxide fertilization. Complete manuring resulted in the same ascorbic acid content as no manuring.

Pfaff and Pfützer (36) found that complete nutrient plants contain more carotene, chlorophyll and ascorbic acid than low nutrient plants. The result of their investigations lead them to conclude that only a relatively loose relationship exists between sugar content and ascorbic acid as a function of variation in fertilizing. Others (37) found that the ascorbic acid content of flowering pea plants is about 50% greater when KNO_3 is used instead of $(NH_4)_2SO_4$. Using superphosphate as fertilizer (38) gave no significant differences in the ascorbic acid content of peas grown with the added nutrient. In growing potatoes (39), inorganic fertilizers gave consistently higher vitamin C values than manuring. Highly improbable in the light of the work of many reputable investigators are the assertions (40) that plants grown without iron or magnesium contain as much or more vitamin C than normal plants. Balks and Pommer (41) studied the influence of various soils on the ascorbic acid content of oats, wheat, rye and winter barley. Seedlings grown in four kinds of soil, namely, chernozem, clay, sand and loam, gave no very marked differences in ascorbic acid values except in the case of chernozem where the value was almost twice that of loam, the lowest in yield.

A new factor (42) influencing the ascorbic acid content of plants seems to be that an increase in the altitude at which plants are grown is accompanied by an increase in the ascorbic acid content. Plants were grown at altitudes of 2,300, 3,650, and 4,000 meters above sea level.

AS A GROWTH-PROMOTING AGENT

There are reports that ascorbic acid has no effect on the action of auxin in the standard *Avena* or pea test (43) and that ascorbic acid appears to be without growth-promoting effect (44).

RELATION TO CELL SIZE

Investigating the accumulation of ascorbic acid in regions of higher metabolic activity, Reid (45) studied the relation of the vitamin to the volume, area and dry weight of individual cells at different stages of growth in root tips of cowpea seedlings. In transition of a cell from the embryonic phase to the elongation phase the vitamin C content increased almost 7-fold. The ascorbic acid in a root cell continues to gain until elongation ceases and maturation begins. Her experiments indicate that ascorbic acid may have a functional relationship at the surface of the cell. Reid suggests that the accumulation of ascorbic acid precedes and possibly conditions cell expansion.

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The Cuticle in Angiosperms	J. H. PRIESTLEY *University of Leeds*
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